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| 13. ABSTRACT (Maximum 200 words)<br>Ultrasonic techniques have been used to characterize the properties of high $T_c$ and other unconventional superconductors. Attenuation and velocity measurements with longitudinal waves have been performed on a large single crystal of $La_{1.85}Sr_{0.15}CuO_4$ . Attenuation and velocity signatures have been observed at the superconducting transition, 37K, and at 27K. The effects observed at the lower temperature are produced by magnetic fluctuations due to an antiferromagnetic transition. Longitudinal ultrasonic attenuation and velocity were measured on a single crystal of $UPT_3$ in high magnetic fields up to 23 T at 192 MHz from 2K up to 35K. Below 17 T, an attenuation peak is observed which is associated with the Kondo Effect. Above 17K, a large attenuation peak was discovered which is due to a metamagnetic transition induced by a crossing of a magnetic energy level with the Fermi Energy. The pontoon technique was used to investigate the attenuation of SAW in a single crystal of YBCO and on thin films of YBCO. Peaks in attenuation are observed slightly below $T_c$ which were enhanced and moved to lower temperatures by a magnetic field. These may be due to melting of the magnetic flux lattice. SAW attenuation and velocity data in the films point to a first order phase transition, around 200 K, which may be a structural transition into a piezoelectric state. |  |   |  |  |  |
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| 14. SUBJECT TERMS<br>YBCO, $La_{1.85}Sr_{0.15}CuO_4$ , longitudinal waves, Surface<br>Acoustic Waves, SAW, ultrasonic attenuation and velocity, magnetic flux lattice,<br>SAW pontoon technique, unconventional superconductors, High $T_c$ superconductors   |  |   |  | 15. NUMBER OF PAGES<br>8   |  |
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# Ultrasonic Characterization of High $T_c$ and Other Unconventional Superconductors

Moisés Levy

## ANNUAL SUMMARY REPORT

June 1, 1994 to June 30, 1995

### A. Description of Project

The objectives of this research project are to characterize the properties of high  $T_c$  superconductors and other unconventional superconductors using ultrasonic techniques in order to provide insights into the mechanisms that are responsible for the unusual superconducting properties of high  $T_c$  superconductors.

### B. Approaches Taken

Bulk acoustic wave attenuation and velocity measurements as a function of temperature and magnetic field have been performed on melt textured and single crystal samples of  $Y_1Ba_2Cu_3O_7$ , on a polycrystalline sample of  $HgBa_2CuO_4$ , and on a single crystal of  $La_{1.85}Sr_{0.15}CuO_4$ .

Ultrasonic measurements on  $UPt_3$  have been carried out in the high magnetic field facility at the Max Planck Institute in Grenoble, France.

The pontoon technique that was developed to launch surface acoustic waves SAW through the surface of platelet shaped single crystals has been extended to launch SAW through films deposited on different substrates.

The resonant ultrasonic spectrometer station has been assembled. Measurements on single crystal silicon rectangular parallelepipeds and on single crystal slivers of the electron-doped superconductor  $Nd_{2-x}Ce_xCuO_4$ , obtained from Brian Maple, University of California San Diego, will be started.

### C. Accomplishments

Ultrasonic attenuation and sound velocity were measured in a single crystal of  $\text{La}_{1.85}\text{Sr}_{0.15}\text{CuO}_4$  with a superconducting transition temperature of 37K that was obtained from Professor K. Kitazawa, University of Tokyo. Longitudinal sound waves were sent along the c-axis of the crystal at frequencies ranging from 25 MHz up to 305 MHz. As a function of temperature, a small peak was observed at around 27K and a large peak at around 37K. These two peaks, especially the small one, became more obvious at the higher frequencies. Simultaneously the velocity exhibited a drop of about 100 ppm below the superconducting transition and a dip at around 27K. From the shape of the velocity changes, it is possible to deduce that the 37K transition involves a quadratic coupling between the order parameter and the strain, which would be expected for a superconducting transition. The 27K transition involves both quadratic and linear coupling. The behavior of the peak in attenuation at 27K is consistent with a relaxation mechanism associated with antiferromagnetic fluctuations which occur above an antiferromagnetic transition. Measurements in a magnetic field of 1.1 Tesla appear to indicate that there is a magnetoelastic interaction threshold at about 200 MHz wherein the interaction abruptly increases above this frequency.

The longitudinal ultrasonic attenuation and velocity were measured on a single crystal of  $\text{UPt}_3$  in high magnetic fields up to 23 T at 192 MHz, from 2K up to 35K. The attenuation peak that had been previously observed at about 12K at zero field was found to shift to lower temperatures with increasing field up to about 17 T. This attenuation behavior is qualitatively consistent with an interaction with a narrow density of states peak, slightly above the Fermi surface, which is associated with the Kondo Effect. However, as the magnetic field is increased above 17 T up to 23 T the energy level of the localized magnetic moments crosses the Fermi surface producing a metamagnetic transition which results in the observation, for the first time,

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of a very large attenuation peak, associated with the crossing of the levels, which overshadows the peak associated with the Kondo Effect.

The pontoon technique, wherein a single crystal platelet is placed as a bridge between two  $\text{LiNbO}_3$  substrates overlaid with SAW interdigital electrodes, was used to measure the attenuation of 168 MHz SAW in a single crystal of YBCO with a superconducting transition temperature  $T_c = 88$  K. A peak in attenuation was observed at  $T_c$  which shifted to lower temperatures and became more pronounced in a magnetic field. This peak in attenuation could be associated with a melting transition in the flux line lattice in the vortex state of the superconductor.

The pontoon technique was also used to investigate, with 250 MHz SAW, YBCO films deposited on  $\text{LiNbO}_3$  substrates, which were too small to have interdigital electrodes deposited directly on them. Again, a strongly field dependent attenuation peak was observed below  $T_c$  which might point to melting of the flux line lattice.

Both the pontoon technique and conventional 164 MHz SAW delay lines were used to study YBCO films around 200 K. Abrupt changes in SAW attenuation and velocity are observed at around 200K on cooling and at around 230K on warming. In order to further investigate these phenomena, a capacitive technique was developed, wherein interdigital capacitors deposited on a glass substrate are brought into close proximity of the films, and the reflection coefficient at 260 MHz and 400 MHz of the capacitors is measured as a function of temperature. Changes in the dielectric constant of the YBCO films are observed at 200K and 230K. These effects may be produced by a first order phase transition to a piezoelectric or ferroelectric crystal structure.

OFFICE OF NAVAL RESEARCH  
PUBLICATIONS/PATENTS/PRESENTATIONS/HONORS REPORT  
1 June 1994 through 30 June 1995

**Ultrasonic Characterization of High  $T_c$  and Other Unconventional Superconductors**  
**Moisés Levy**

- a. Number of Papers Submitted to Referred Journals but not yet published: 3
  1. "High Field Ultrasonic Measurements on  $U\text{Pt}_3$ ," S. W. Lin, I. Kouroudis, A. G. M. Jansen, P. Wyder, B. Luthi, D. G. Hinks, J. B. Ketterson, M. Levy and Bimal K. Sarma (Submitted to Proceedings of the Conference on Physical Phenomena at High Magnetic Fields, World Publishing Co., Singapore).
  2. "Ultrasonic Velocity and Attenuation Measurements at the Metamagnetic Transition in  $U\text{Pt}_3$ ," S. W. Lin, I. Kouroudis, A. G. M. Jansen, P. Wyder, B. Luthi, D. G. Hinks, J. B. Ketterson, M. Levy, and Bimal K. Sarma (to be published in the Journal of Low Temperature Physics).
  3. "Ultrasonic Attenuation and Sound Velocity Changes in a Superconducting  $\text{La}_{2x}\text{Sr}_x\text{CuO}_4$  Single Crystal," Hong Zhang, Mark J. McKenna, Carsten Hucho, Bimal K. Sarma, Moises Levy, T. Kimura, K. Kishio and K. Kitazawa (Submitted to Physica B).
- b. Number of papers published in Referred Journal: 2
  1. "Ultrasonic Investigation of Amorphous Superconducting Films," J. Schmidt, M. Levy and A. F. Hebard, Phys. Rev. B 50, 3988-3994 (1984).
  2. "Superconducting Phase Diagrams of  $U\text{Pt}_3$  from Ultrasonic Velocity Measurements," S. W. Lin, J. B. Ketterson, M. Levy and Bimal K. Sarma, Physica B 204, 233-241 (1995).
- c. Number of Books or Chapters Submitted but not yet published: 3
  1. "Surface Acoustic Wave Measurements on Superconducting Films," M. Levy and S. Schneider (chapter to be published in Mechanical Spectroscopy, editor L. B. Magalas, publisher Elsevier Science Publishers Ltd.)
  2. "Surface Waves in Solids and Ultrasonic Properties," Moises Levy and Susan C. Schneider, Handbook of Acoustics, Edited by Malcolm J. Crocker (To be published by John Wiley & Sons, Inc.).

3. "Multiple Superconducting Phases and Unconventional Superconductivity in  $\text{Upt}_3$ ," Bimal K. Sarma, S. W. Lin, M. Levy, S. Adenwalla, and J. B. Ketterson, Proceedings of the S. N. Bose Centenary Celebration (Edited by M. Dutta).
- d. Number of Books or Chapters Published: 1
1. 1994 IEEE Ultrasonics Symposium Proceedings, (1911 pages 94CH3468-6, Eds. M. Levy, S. C. Schneider and B. R. McAvoy, New Jersey, 1994).
- e. Number of Printed Technical Reports and Non-referred Paper: 1
1. "Superconducting Interdigital Transducers," J. Feller, M. Levy, B. K. Sarma, H. Fredricksen, D. Ritums, N. J. Wu, X. Y. Li, and A. Ignatiev, 1994 IEEE Ultrasonics Symposium Proceedings, pages 825-828 (94CH3468-6; eds. M. Levy, S. C. Schneider and B. R. McAvoy, New Jersey, 1995).
- f. Number of Patents Filed: 0
- g. Number of Patents Granted: 0
- h. Number of Invited Presentations at Workshops or Professional Society Meetings: 0
- i. Number of Presentations at Workshops or Professional Society Meetings: 12
1. "Proposed RUS Measurements on High  $T_c$  Single Crystals," Mark J. McKenna, Bimal K. Sarma and Moises Levy, First Resonant Ultrasonic Spectroscopy Workshop CORUS, August 25-27, 1994, Milwaukee, WI.
  2. "High  $T_c$  SAW Devices and Measurements Near the Superconducting Transition," J. Feller, M. Levy, B. K. Sarma, H. Fredricksen, D. Ritums, N. J. Wu, X. Y. Li, and A. Ignatiev, 1994 IEEE Ultrasonics Symposium, Cannes, France, November 1-4, 1994.
  3. "Measurements of Ultrasonic Attenuation and Sound Velocity in a Single Crystal of  $(\text{La}_{1-x}\text{Sr}_x)_2\text{CuO}_4$ ," Hong Zang, Mark J. McKenna, Bimal K. Sarma, Moises Levy, T. K. Kimura, K. Kishio, and K. Kitazawa, 128th Meeting of the Acoustical Society of America, November 28 to December 2, 1994, Austin, TX.
  4. "High Field Ultrasonic Studies on the Heavy Fermion State of  $\text{Upt}_3$ ," B. K. Sarma, M. Levy, S. W. Lin, J. B. Ketterson, I. Kouroudis, B. Luthi, A. G. M. Jansen and P. Wyder, APS 1995 March Meeting, 20-24 March 1995, San Jose, California, Bull. APS, Vol. 40, No. 1, C-16-2, page 128 (1995).
  5. "Surface Acoustic Wave Investigation of Mixed State Phases in Thin Films of  $\text{Y}_1\text{Ba}_2\text{Cu}_3\text{O}_7$ ," J. Feller, C. Hucho, M. McKenna, M. Levy, B. K. Sarma and J. Gavaler, APS 1995 March Meeting, 20-24 March 1995, San Jose, California, Bull. APS, Vol. 40, No. 1, E-10-1, page 188 (1995).

6. "Surface Acoustic Wave Investigation of Twinned Single Crystals of  $Y_1Ba_2Cu_3O_7$ ," R. Gaffney, C. Hucho, M. McKenna, M. Levy and B. K. Sarma, APS 1995 March Meeting, 20-24 March 1995, San Jose, California, Bull. APS, Vol. 40, No. 1, E-10-2, page 188 (1995).
7. "Superconducting and Magnetic Transitions in  $(La_{(1-x)}Sr_x)_2CuO_4$  Single Crystal by Ultrasonic Measurements," Hong Zhang, Mark J. McKenna, Bimal Sarma, Moises Levy, T. Kimura, K. Kishio and K. Kitazawa, APS 1995 March Meeting, 20-24 March 1995, San Jose, California, Bull. APS, Vol. 40, No. 1, I-12-9, page 390 (1995).
8. "Magnetic Field Studies of Superconducting Transition in  $(La_{(1-x)}Sr_x)_2CuO_4$  Single Crystal by Ultrasonic Measurements," M. J. McKenna, Hong Zhang, Bimal K. Sarma, Moises Levy, T. Kimura, K. Kishio and Kitazawa, 129th Meeting of ASA, 30 May - 3 June, 1995, Washington, D. C., JASA Vol. 97, No. 5, Pt2, 3aPA5, page 3326 (May 1995).
9. "Surface Acoustic Wave Investigation of Phase Transitions in  $Y_1Ba_2Cu_3O_7$  Films, J. Feller, C. Hucho, R. Gaffney, M. J. McKenna, B. K. Sarma, and M. Levy, 129th Meeting of ASA, 30 May - 3 June, 1995, Washington, D. C., JASA Vol. 97, No. 5, Pt2, 5aPA1, page 3394 (May 1995).
10. "High Field Ultrasonic Measurements on  $UPt_3$ ," S. W. Lin, I. Kouroudis, A. G. M. Jansen, P. Wyder, B. Luthi, D. G. Hinks, J. B. Ketterson, M. Levy and Bimal K. Sarma, Conference on Physical Phenomena at High Magnetic Fields, May 6-9, 1995, Tallahassee, Fl.
11. "Ultrasonic Velocity and Attenuation Measurements at the Metamagnetic Transition in  $UPt_3$ ," S. W. Lin, I. Kouroudis, A. G. M. Jansen, P. Wyder, B. Luthi, D. G. Hinks, J. B. Ketterson, M. Levy, and Bimal K. Sarma, Symposium on Quantum Fluids and Solids, June 13-17, 1995, Cornell University, Ithaca, N. Y.
12. "Ultrasonic Attenuation and Sound Velocity Changes in Superconducting  $La_{(2x)}Sr_xCuO_4$  Single Crystal," Hong Zhang, Mark. J. McKenna, Carsten Hucho, Bimal K. Sarma, Moises Levy, T. Kimura, K. Kishio and K. Kitazawa, 15th International Congress on Acoustics, 26-30 June, 1995, Trondheim, Norway.

j. Honors/Awards/Prizes for Grant Employee: 3

Elected Fellow of the IEEE

Elected Chair of the IEEE Applied Superconductivity Committee and of the Editorial Board of the IEEE Transactions on Applied Superconductivity

Appointed Co-editor of the IEEE Ultrasonics Symposium Proceedings

- k. Total Number of Graduate Students and Post Docs Supported at Least 25%, This Year  
On This Grant

Graduate Students: 5

Post Docs: 1

Debashis Dasgupta

Mark J. McKenna

Jeffrey Feller

Ron Gaffney

Joseph Herro

Hang Zhang

ML-774WP